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# TECHNICAL NOTE

## D-1162

PERFORMANCE OF SMALL (100-LB THRUST) ROCKET MOTORS  
USING COAXIAL INJECTION OF HYDRAZINE  
AND NITROGEN TETROXIDE

By Joseph F. Wasserbauer and William Tabata

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Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
WASHINGTON

December 1961



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## SUMMARY

An investigation was conducted on a small (approximately 100-lb thrust) rocket using coaxial injection of hydrazine and nitrogen tetroxide. Characteristic-velocity efficiencies of 94 percent of the theoretical shifting equilibrium value were obtained at a chamber pressure of about 300 pounds per square inch using a 21-tube injector and a combustion chamber characteristic length of 10 inches. Performance at lower chamber pressures could be improved by reducing contraction ratio and thereby increasing the combustion chamber length and injector pressure drop, which would tend to promote better mixing. Calculations based on experimental data showed a vacuum specific impulse of 305 seconds with a nozzle area ratio of 50.

## INTRODUCTION

Space mission studies have indicated the need for small rocket motors of low thrust (of the order of 100 lb) for attitude control, mid-course trajectory corrections, rendezvous, and so forth. For such space applications the storable liquid propellants are attractive because they indicate potential high performance, have reasonable handling and storage qualities, and are hypergolic. Accordingly, hydrazine ( $N_2H_4$ ) and nitrogen tetroxide ( $N_2O_4$ ) were selected as the propellants for the present study.

Recent investigations of motors using coaxial injection of JP-4 fuel and liquid oxygen have indicated that high performance can be obtained with low-characteristic-length chambers (ref. 1). The use of coaxial injection with storable propellants should likewise result in small effective chamber lengths without compromising performance. Therefore, an investigation was undertaken to determine the performance of  $N_2O_4$  and  $N_2H_4$  using the coaxial injection principle. Parameters

which influence combustion performance such as the number of injection points, injection point spacing, chamber pressure, mixture ratio, and chamber characteristic length were investigated. The tests were conducted in heat-sink zirconia-coated combustion chambers with a nominal thrust level of 100 pounds. The chamber pressure was varied from approximately 100 to 300 pounds per square inch.

## APPARATUS

A schematic diagram of the oxidant and fuel systems is shown in figure 1. Each system consisted of a 1-cubic-foot propellant tank, a shutoff valve, a wire screen filter (160 mesh, 0.0025-in.-diam. wire), a turbine-type flowmeter, and a flow-control valve. The propellant tanks were pressurized by nitrogen. A nitrogen purge was provided for each propellant system.

The hydrazine was 98.4 percent pure and the nitrogen tetroxide was 99.5 percent pure. The time histories of all data were recorded on a direct-reading oscillograph. Pressures were measured in the combustion chamber, injector, propellant tanks, and altitude chamber by pressure transducers. The propellant flows were measured by turbine-type flowmeters. The propellants were maintained at constant temperature by immersing the propellant tanks in an ice bath. Heat-sink motors with two combustion chamber diameters were used. Shown in figure 2 are the nozzle and chamber segments for the 1.03- and 1.50-inch-diameter motors. The nozzle and chamber segments were bolted together in series to obtain variations in length. Aluminum gaskets were used as a seal between each segment. All segments of the heat-sink motor were coated with zirconia except the injector face. The chamber segments were fabricated from mild steel, whereas the nozzle segments were made from copper.

The injector head assembly (fig. 3(a)) could be used with either the 1.03- or 1.50-inch-diameter chambers. The injector was designed so that the fuel flowed through the annuli and the oxidant through the center tubes. Views of injector face plate configurations with tube and orifice dimensions are shown in figure 3(b). All injectors were designed with essentially the same flow characteristics (pressure differential as function of weight flow), as shown in figure 4. As the number of injection points was increased or decreased, the hole area and annulus area for each injection point was decreased or increased, respectively, to maintain the flow characteristics of figure 4. Photographs of the various components of the 1.03- and 1.50-inch-diameter motors are shown in figure 5.

## PROCEDURE

For each firing, an electronic controller was used to set mixture ratio and desired chamber pressure. The controller was programed to vary mixture ratio in five steps of about 2 seconds of firing time each or to give only one mixture-ratio setting with firing durations of 4 to 8 seconds. A typical trace for a firing at one mixture ratio is shown in figure 6.

Before and after a complete run (which consisted of several firings) the nozzle throat diameter was measured to detect any erosion. If any erosion occurred, the data were corrected by assuming a linear variation of throat area with firing time.

## RESULTS AND DISCUSSION

The performance was determined for a series of small (100-lb) rockets having coaxial injection by variations in motor geometry such as changing the number of injection points, spacing between the injection points, and throat contraction ratio. Experimental performance data are listed in tables I to IV for all injector and chamber configurations. The data were corrected for momentum pressure loss in the chamber, and calculations for efficiency in characteristic velocity  $c^*$  were based on theoretical shifting equilibrium values. Corrections for heat loss to the chamber wall were not taken into consideration.

In order to determine the number of injection points (or injection tubes) necessary for efficient operation, injectors were constructed with 45, 21, 9, and 7 tubes. Of all the injectors tested, the 21-tube (0.090-in. spacing) injector gave the best performance (fig. 7). The peak efficiency in  $c^*$  of 94 percent was obtained with the 21-tube injector and remained constant for a mixture-ratio range of about 0.60 to 1.00. The performance in  $c^*$  efficiency was fairly flat and varied about 4.3 percent from the peak efficiency over the mixture-ratio range investigated. At a mixture ratio of 0.78 and  $c^*$  efficiency of 94 percent, the injector pressure differential  $\Delta P$  was approximately 57 pounds per square inch for each propellant. This combination of high  $c^*$  efficiency and equal injection pressures could simplify the design of a complete rocket system and could be achieved maintaining equal supply pressures in both propellant tanks.

In this study, the number of injection points was varied from 21 to 7, 9, or 45. The data for the 7- and 45-tube injectors are presented in tables III and IV. Either reducing or increasing the number of injection points from 21 resulted in lower overall performance. It had been expected that increasing the number of injection points would give better mixing through smaller drop size (ref. 2). Rough burning and injector

burnout were common for these injector configurations. The square 9-tube injector pattern apparently produced a flow of combusting gases which caused the particular lobelike injector face burnout shown in figure 8. The close injection point spacing and right angle corner between the injector face and the chamber wall probably induced flow recirculation, while the square injection point arrangement caused the particular burnout pattern. No data are presented for the 9-tube injector because of almost immediate burnout after ignition.

Data presented in subsequent figures are for the 21-tube injector and a mixture-ratio range of 0.80 to 1.00, since peak performance was obtained in this range for all configurations tested. The effect of injection point spacing on efficiency at various characteristic lengths and chamber pressures for the 21-tube injector is presented in figure 9. Of the three tube spacings investigated the 0.090-inch tube spacing gave the highest performance over the range of chamber pressure and chamber characteristic length  $L^*$ . As the chamber pressure increased the efficiency also increased. This might be expected, because the higher chamber pressure and the higher injector pressure drop resulting from higher propellant flows tend to promote better mixing of the propellants (refs. 3 and 4).

The chamber pressures attainable with various contraction ratios were computed using continuity relations and are indicated in figure 10 for the range of propellant flows of figure 4. Contraction ratio was varied by varying throat diameter and maintaining constant chamber diameter. Figure 10 shows that, as the contraction ratio is decreased, the total propellant flow rate for a given chamber pressure is increased, and this results in higher injection pressure drops. Also, in order to maintain constant  $L^*$  with decreasing contraction ratio, the chamber length was increased. Therefore, at constant  $L^*$  the increased chamber length and higher injector pressure drops (tending to promote better mixing) can be used to explain the improved efficiency that is obtained at low chamber pressures (fig. 11). For the same reason there is a general trend of improved  $c^*$  efficiency with increasing chamber pressure. Figure 11 also shows the effect of  $L^*$  on performance. Increasing  $L^*$  from 7.5 to 10 inches broadens the operating range; that is, with an  $L^*$  of 7.5 inches the  $c^*$  efficiency is good at the higher chamber pressures with a rapid decrease in performance as the chamber pressure is lowered. For an  $L^*$  of 10 inches the decline in  $c^*$  efficiency is not as rapid as the chamber pressure is lowered. There is a further slight improvement in this respect in going to an  $L^*$  of 15 inches.

For the best coaxial injector (21-tube, 0.090-in. injection point spacing) and an  $L^*$  of 10 inches, calculations were made of vacuum specific impulse based on experimental data. A vacuum thrust coefficient of 1.8, a nozzle area ratio of 50, and a ratio of specific heats of 1.30 were assumed. The results (fig. 12) showed that vacuum impulse as

high as 305 seconds can be obtained using coaxial injection and low chamber characteristic lengths. For a fixed motor geometry (i.e., fixed contraction ratio) the reduction in vacuum specific impulse varied from 4.2 to 8.5 percent when chamber pressure was reduced by 33 percent at any particular oxidant-fuel ratio. This could be a desirable feature for variable-thrust motors.

### CONCLUSION

An investigation was conducted on a small (approx. 100-lb thrust) rocket using coaxial injection of hydrazine and nitrogen tetroxide. Characteristic-velocity efficiencies as high as 94 percent of the theoretical shifting equilibrium values were obtained using a 21-tube injector (with 0.090-in. injection point spacing) and a combustion chamber with a characteristic length of 10 inches. Performance at lower chamber pressures could be improved by reducing contraction ratio and thereby increasing the combustion chamber length and injector pressure drop, which would tend to promote improved mixing. Calculations based on experimental data showed that a vacuum specific impulse of 305 seconds could be obtained with a nozzle area ratio of 50.

Lewis Research Center

National Aeronautics and Space Administration  
Cleveland, Ohio, September 18, 1961

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TABLE I. - 1.50-INCH-DIAMETER CHAMBER WITH 21-TUBE INJECTOR

[Spacing, 0.090 in.]

Chamber pressure, lb/sq in. abs	Oxidant flow, lb/sec	Fuel flow, lb/sec	Oxidant-fuel ratio	Characteristic velocity, c*, ft/sec	c* efficiency	Oxidant pressure drop	Fuel pressure drop
Contraction ratio, 6.25; characteristic length, 5 in.							
243	0.180	0.334	0.539	4280	77.5	32	207
241	.214	.234	.915	4880	84.1	41	102
237	.239	.213	1.122	4750	81.8	54	87
237	.264	.203	1.300	4595	79.1	69	82
246	.295	.195	1.513	4550	80.7	74	79
292	.216	.319	.678	4950	87.3	40	193
292	.225	.322	.699	4840	85.0	45	193
292	.230	.324	.710	4780	83.8	38	190
297	.310	.242	1.280	4875	84.4	74	110
294	.342	.232	1.474	4635	81.8	99	108
295	.365	.216	1.690	4600	83.3	112	90
Contraction ratio, 6.25; characteristic length, 10 in.							
249	0.178	0.249	0.715	5410	94.9	23	43
249	.196	.240	.817	5240	90.8	35	44
247	.204	.237	.860	5260	91.2	33	39
250	.216	.226	.956	5140	87.4	42	39
250	.243	.216	1.125	4900	84.2	52	36
247	.325	.207	1.570	4540	81.1	86	31
222	.181	.226	.801	5290	92.1	24	32
222	.206	.220	.936	5150	88.9	32	32
222	.202	.212	.953	5130	88.4	32	31
222	.258	.195	1.323	4645	80.9	56	26
196	.153	.226	.677	5265	93.0	13	34
192	.173	.214	.808	5090	89.6	27	38
192	.230	.202	1.139	4480	77.4	49	38
196	.263	.191	1.377	4312	75.5	58	29
Contraction ratio, 6.25; characteristic length, 15 in.							
190	0.141	0.179	0.788	5360	93.1	86	88
219	.157	.195	.805	5610	97.6	94	95
199	.146	.174	.839	5610	97.2	86	87
208	.200	.229	.873	4375	75.9	48	44
Contraction ratio, 3.52; characteristic length, 5 in.							
167	0.208	0.271	0.768	5555	97.2	185	179
163	.219	.271	.808	5300	92.2	46	53
165	.228	.266	.857	5330	92.4	50	52
165	.233	.261	.893	5330	92.2	52	51
160	.241	.255	.945	5140	88.7	58	50
165	.235	.248	.948	5360	92.4	175	164
159	.248	.250	.993	5090	87.7	61	47
155	.227	.226	1.005	5360	92.4	178	156
154	.261	.238	1.097	4920	85.0	66	43
164	.354	.259	1.366	4190	73.6	136	66
157	.297	.190	1.562	5050	90.5	195	135
Contraction ratio, 3.52; characteristic length, 10 in.							
205	0.247	0.360	0.686	5292	93.4	41	61
216	.294	.336	.875	5370	92.9	65	52
209	.288	.321	.898	5378	92.9	63	54
209	.301	.318	.947	5390	93.0	71	60
208	.334	.295	1.132	5280	91.4	88	52
209	.380	.281	1.352	4955	86.7	109	42
211	.431	.281	1.532	4735	84.5	138	51
193	.244	.339	.720	5290	93.0	52	73
192	.260	.311	.836	5370	93.3	54	60
193	.284	.291	.976	5360	92.5	61	51
188	.300	.273	1.099	5240	90.6	71	47
134	.185	.257	.720	4840	85.0	45	59
148	.216	.269	.803	4875	84.8	52	64
146	.222	.270	.823	4740	82.4	54	61
164	.246	.272	.905	5060	87.4	58	54
159	.250	.263	.951	4950	85.5	61	54
115	.160	.200	.800	5100	88.9	58	35
117	.217	.190	1.143	4595	79.6	45	24

TABLE I. - Continued. 1.50-INCH-DIAMETER CHAMBER WITH 21-TUBE INJECTOR

[Spacing, 0.090 in.]

Chamber pressure, lb/sq in. abs	Oxidant flow, lb/sec	Fuel flow, lb/sec	Oxidant-fuel ratio	Characteristic velocity, c*, ft/sec	c* efficiency	Oxidant pressure drop	Fuel pressure drop
Contraction ratio, 3.25; characteristic length, 16 in.							
217	0.247	0.440	0.562	5240	94.5	50	100
214	.285	.381	.748	5325	93.3	67	78
213	.300	.360	.834	5350	93.1	76	68
211	.316	.344	.919	5295	91.7	86	62
213	.399	.307	1.300	5000	87.7	132	50
162	.184	.326	.565	5265	94.8	30	58
162	.218	.292	.747	5265	92.3	41	47
162	.250	.269	.930	5170	89.8	55	42
162	.280	.253	1.107	5040	87.8	63	36
162	.305	.238	1.281	4945	86.2	76	32
162	.332	.228	1.455	4795	84.9	95	31
119	.151	.244	.619	4995	89.0	33	51
107	.182	.214	.851	4480	77.9	32	25
114	.106	.171	1.114	5150	89.4	26	20
122	.277	.173	1.602	4490	81.3	71	21
Contraction ratio, 2.49; characteristic length, 7.5 in.							
130	0.274	0.276	0.994	5230	91.3	68	58
136	.313	.290	1.080	5000	86.6	85	62
135	.387	.262	1.459	4635	82.4	125	53
115	.201	.297	.677	5120	90.4	40	67
116	.213	.297	.764	5220	91.4	42	22
115	.226	.270	.837	5140	89.2	47	47
113	.228	.266	.858	5070	87.8	53	49
115	.230	.265	.869	5160	89.5	47	53
113	.249	.257	.969	4960	86.0	61	54
119	.336	.233	1.442	4625	82.5	99	43
Contraction ratio, 2.49; characteristic length, 10 in.							
137	0.272	0.330	0.825	5270	91.7	63	89
137	.276	.316	.875	5330	92.4	63	82
137	.292	.300	.973	5310	91.7	69	74
137	.329	.278	1.183	5150	89.4	87	65
138	.326	.275	1.185	5220	90.6	83	64
117	.224	.304	.737	5240	91.9	44	75
117	.225	.305	.738	5220	91.6	44	75
117	.228	.370	.743	5170	90.5	44	75
118	.240	.294	.817	5220	90.9	51	71
117	.258	.282	.915	5150	89.2	57	67
117	.280	.267	1.050	4970	86.0	66	59
113	.402	.234	1.717	4180	76.6	128	47
97	.187	.277	.675	5020	88.7	35	68
97	.296	.286	1.035	4030	69.7	75	49
Contraction ratio, 2.49; characteristic length, 15 in.							
139	0.245	0.314	0.781	5530	96.1	61	58
138	.264	.299	.883	5470	94.6	64	56
138	.271	.306	.886	5320	92.2	74	56
139	.280	.312	.898	5230	90.5	71	53
139	.292	.283	1.031	5380	93.2	77	52
139	.311	.267	1.165	5350	93.0	81	46
136	.354	.245	1.445	5050	89.6	114	39
119	.222	.278	.799	5290	92.4	51	50
119	.236	.269	.878	5250	91.0	57	47
119	.241	.255	.945	5330	92.5	58	40
119	.297	.241	1.232	4920	85.4	70	40
120	.319	.224	1.425	4910	86.9	98	33
99	.203	.212	.957	5310	92.0	153	138
100	.212	.199	1.065	5410	93.7	149	133
102	.220	.193	1.140	5510	95.6	145	128

TABLE I. - Concluded. 1.50-INCH-DIAMETER CHAMBER WITH 21-TUBE INJECTOR

[Spacing, 0.090 in.]

Chamber pressure, lb/sq in. abs	Oxidant flow, lb/sec	Fuel flow, lb/sec	Oxidant-fuel ratio	Characteristic velocity, $c^*$ , ft/sec	$c^*$ efficiency	Oxidant pressure drop	Fuel pressure drop
Contraction ratio, 1.99; characteristic length, 7.5 in.							
98	0.219	0.279	0.785	5180	90.4	42	62
99	.228	.273	.835	5210	90.6	45	59
99	.242	.258	.938	5220	90.4	51	54
99	.261	.243	1.074	5170	89.6	54	49
99	.327	.243	1.345	4580	80.9	100	51
78	.137	.271	.506	5040	92.1	19	61
78	.137	.270	.507	5050	92.2	22	61
78	.148	.257	.576	5080	91.0	22	54
78	.147	.258	.578	5040	90.6	22	54
80	.298	.238	1.252	3930	69.7	90	55
78	.305	.221	1.380	3910	69.4	92	42
Contraction ratio, 1.99; characteristic length, 10 in.							
95	0.231	0.286	0.809	4870	84.8	45	64
95	.234	.275	.852	4945	85.9	42	61
99	.336	.238	1.411	4580	80.7	110	51
94	.325	.229	1.420	4500	79.7	45	100
103	.335	.233	1.438	4730	85.3	66	122
95	.332	.229	1.450	4490	79.9	46	109
69	.229	.228	1.003	4005	69.4	45	51
69	.259	.226	1.147	3770	65.7	49	71
71	.270	.217	1.242	3660	67.6	77	46
71	.284	.217	1.308	3750	65.8	85	46

TABLE II. - 1.03-INCH-DIAMETER CHAMBER WITH 21-TUBE INJECTOR

[Contraction ratio, 3.00.]

Chamber pressure, lb/sq in. abs	Oxidant flow, lb/sec	Fuel flow, lb/sec	Oxidant-fuel ratio	Characteristic velocity, c*, ft/sec	c* effi- ciency	Oxidant pressure drop	Fuel pressure drop
Spacing, 0.090 in.; characteristic length, 6.15 in.							
267	0.203	0.266	0.763	5065	88.3	51	74
259	.213	.257	.829	4905	85.2	73	80
247	.214	.238	.899	4860	84.0	64	77
259	.228	.252	.905	4805	83.0	75	77
259	.235	.246	.956	4795	82.7	83	73
249	.240	.231	1.038	4705	81.1	121	63
261	.246	.235	1.048	4830	83.3	71	60
242	.189	.242	.781	5000	87.2	51	65
232	.204	.228	.895	4775	82.5	62	68
211	.183	.216	.848	4705	81.7	59	64
217	.194	.215	.903	4725	81.6	67	79
210	.189	.209	.904	4700	81.2	59	62
208	.194	.204	.951	4650	80.2	61	59
200	.188	.195	.964	4650	80.2	54	60
212	.202	.200	1.010	4695	80.9	61	58
206	.214	.190	1.127	4540	78.4	69	58
171	.138	.175	.789	4830	84.2	38	45
166	.136	.172	.791	4795	83.6	38	49
173	.149	.172	.866	4800	83.4	43	47
169	.155	.176	.881	4540	78.6	49	61
172	.160	.168	.953	4665	80.4	48	49
173	.170	.164	1.037	4610	79.5	55	49
Spacing, 0.090 in.; characteristic length, 9.03 in.							
278	0.229	0.296	0.774	4805	83.9	50	91
279	.238	.282	.844	4870	84.4	56	85
278	.239	.282	.847	4840	83.9	72	102
263	.238	.265	.898	4750	82.4	67	83
277	.238	.263	.905	5020	86.9	77	59
288	.250	.275	.910	4980	86.2	60	80
281	.245	.252	.973	5130	88.4	85	95
239	.191	.246	.777	4965	86.7	60	84
238	.197	.238	.828	4965	86.1	57	72
243	.205	.232	.884	5050	87.6	60	75
237	.216	.228	.948	4845	83.6	69	78
239	.230	.222	1.036	4800	82.8	66	69
247	.243	.220	1.105	4845	83.6	70	61
250	.258	.215	1.200	4800	83.0	68	54
210	.179	.213	.841	4865	84.4	57	73
207	.183	.210	.871	4780	82.9	62	73
204	.186	.201	.925	4780	82.4	59	72
212	.200	.197	1.015	4850	83.5	59	68
214	.211	.190	1.110	4850	83.6	71	66
Spacing, 0.090 in.; characteristic length, 9.65 in.							
250	0.200	0.254	0.788	5350	93.4	43	76
254	.207	.250	.828	5190	90.2	43	76
248	.222	.241	.921	5070	87.6	55	77
248	.230	.234	.983	5090	87.8	79	74
242	.241	.224	1.076	5010	86.4	60	66
237	.212	.241	.880	5190	89.8	55	82
221	.171	.221	.774	4965	86.8	40	62
217	.172	.228	.755	5020	87.7	40	68
215	.174	.209	.832	4975	86.4	41	63
219	.189	.211	.896	4910	84.9	52	68
219	.200	.207	.966	4895	84.4	50	64
214	.209	.201	1.040	4780	82.4	58	63

TABLE II. - Continued. 1.03-INCH-DIAMETER CHAMBER WITH 21-TUBE INJECTOR

[Contraction ratio, 3.CO.]

Chamber pressure, lb/sq in. abs	Oxidant flow, lb/sec	Fuel flow, lb/sec	Oxidant-fuel ratio	Characteristic velocity, c*, ft/sec	c* efficiency	Oxidant pressure drop	Fuel pressure drop
Spacing, 0.090 in.; characteristic length, 10.7 in.							
311	0.200	0.357	0.560	5200	93.5	40	78
311	.236	.310	.762	5340	93.2	54	58
311	.262	.274	.957	5460	94.0	70	46
311	.291	.255	1.142	5360	92.5	86	41
311	.319	.240	1.328	5250	91.4	107	34
311	.350	.229	1.528	5090	90.4	124	32
301	.230	.242	.951	5660	97.4	50	35
286	.192	.332	.579	5190	94.3	35	67
285	.222	.292	.760	5300	92.5	52	53
285	.246	.260	.947	5400	93.0	62	43
285	.272	.236	1.152	5390	93.0	75	34
285	.299	.222	1.347	5270	91.8	93	30
288	.326	.216	1.510	5140	91.2	110	25
246	.190	.248	.766	5130	89.6	43	45
255	.219	.230	.952	5230	90.0	46	30
255	.242	.212	1.141	5190	89.6	66	32
250	.259	.195	1.327	5100	88.9	66	22
250	.283	.187	1.513	4945	87.8	83	22
236	.190	.252	.754	5170	90.2	44	44
241	.182	.229	.795	5310	92.4	43	39
229	.188	.227	.828	5020	87.1	48	44
239	.190	.219	.867	5220	90.3	45	37
243	.193	.213	.881	5370	93.0	42	34
226	.204	.216	.944	5250	90.4	42	29
231	.200	.209	.957	5090	87.6	53	39
235	.232	.200	1.160	5370	92.6	60	28
236	.255	.191	1.334	5190	90.4	65	24
236	.276	.183	1.506	5160	91.6	75	20
211	.184	.235	.783	4960	86.4	61	62
205	.194	.205	.947	5100	87.8	53	45
212	.223	.193	1.155	5070	87.7	60	38
210	.236	.177	1.333	5070	88.3	58	23
211	.260	.170	1.530	4905	87.1	70	22
Spacing, 0.071 in.; characteristic length, 6.15 in.							
294	0.255	0.306	0.833	4690	81.4	54	88
293	.264	.305	.866	4610	80.0	73	99
292	.273	.289	.945	4655	80.3	83	94
299	.282	.289	.976	4690	80.9	96	102
278	.253	.286	.885	4620	79.9	76	96
247	.218	.265	.823	4580	79.5	60	89
244	.217	.262	.828	4560	79.1	54	82
244	.216	.259	.834	4600	79.8	53	77
245	.230	.252	.913	4550	78.6	81	105
255	.237	.251	.944	4680	80.8	61	74
252	.247	.244	1.012	4600	79.2	68	72
215	.183	.233	.786	4625	80.6	39	55
209	.189	.226	.836	4515	78.4	52	61
196	.188	.210	.895	4410	76.2	54	63
206	.195	.218	.895	4465	77.2	54	60
204	.214	.206	1.039	4350	74.9	63	60
165	.138	.221	.625	4115	73.2	48	79
173	.140	.213	.650	4390	77.7	70	82
173	.145	.212	.684	4340	76.5	83	112

TABLE II. - Concluded. 1.03-INCH-DIAMETER CHAMBER WITH 21-TUBE INJECTOR

[Contraction ratio, 3.00.]

Chamber pressure, lb/sq in. abs	Oxidant flow, lb/sec	Fuel flow, lb/sec	Oxidant-fuel ratio	Characteristic velocity, c*, ft/sec	c* efficiency	Oxidant pressure drop	Fuel pressure drop
Spacing, 0.071 in.; characteristic length, 9.65 in.							
192	0.161	0.229	0.703	4390	77.2	64	82
208	.188	.261	.721	4135	72.7	76	97
213	.197	.252	.782	4230	73.8	58	69
212	.166	.220	.755	4900	85.7	68	85
218	.179	.214	.837	4950	85.9	68	74
211	.210	.247	.850	4120	71.4	65	73
217	.191	.203	.941	4910	84.7	73	75
215	.198	.198	1.000	4840	83.5	77	73
Spacing, 0.071 in.; characteristic length, 10.7 in.							
203	0.151	0.233	0.648	4710	83.5	72	57
224	.158	.227	.696	5100	89.8	34	54
230	.178	.220	.809	5140	89.4	54	70
234	.185	.219	.845	5100	88.4	53	64
232	.193	.208	.928	5110	88.3	62	72
238	.198	.204	.971	5250	90.4	60	55
Spacing, 0.100 in.; characteristic length, 10.7 in.							
294	0.296	0.295	1.002	4660	80.4	(a)	(a)
294	.297	.290	1.025	4730	81.6		
294	.337	.250	1.349	4700	82.4		
288	.354	.228	1.551	4640	83.0		
244	.309	.220	.405	4140	73.2		
244	.219	.233	.940	4780	82.6		
243	.227	.231	.984	4770	82.7		
243	.238	.237	1.005	4660	80.6		
243	.240	.219	1.095	4780	82.8		
239	.267	.220	1.213	4455	77.6		
193	.198	.225	.880	4200	72.9		
193	.196	.250	.957	3960	68.6		
193	.230	.213	1.080	4090	70.8		
193	.230	.210	1.096	4070	70.5		
192	.240	.200	1.200	4060	70.7		

<sup>a</sup>Pressure transducer lines were plugged for this test.

TABLE III. - 1.03-INCH-DIAMETER CHAMBER WITH 7-TUBE INJECTOR

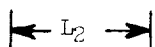
[Contraction ratio, 3.00; characteristic length, 10.7 in.]

Chamber pressure, lb/sq in. abs	Oxidant flow, lb/sec	Fuel flow, lb/sec	Oxidant-fuel ratio	Characteristic velocity, c*, ft/sec	c* efficiency	Oxidant pressure drop	Fuel pressure drop
Spacing, 0.201 in.							
296	0.240	0.304	0.790	5030	87.7	52	64
297	.254	.299	.850	4965	86.0	58	61
297	.273	.288	.968	4895	84.3	66	47
246	.191	.253	.755	5120	89.5	36	53
249	.197	.231	.853	5150	89.2	33	43
249	.214	.248	.863	4985	86.2	39	43
249	.204	.229	.891	5090	88.0	38	43
246	.242	.232	1.043	4800	82.5	58	43
244	.342	.212	1.613	4071	73.2	106	27
202	.142	.231	.615	5005	89.2	21	42
200	.137	.215	.638	5250	93.1	14	27
198	.160	.198	.808	5110	88.9	14	36
198	.173	.193	.897	5000	86.4	27	23
198	.197	.186	1.059	4780	82.4	35	21
Spacing, 0.100 in.							
292	0.351	0.304	1.154	4495	77.6	148	111
292	.368	.292	1.259	4460	77.4	158	97
277	.347	.278	1.247	4465	77.4	144	92
274	.350	.268	1.305	4470	77.8	141	86
255	.358	.236	1.516	4325	76.8	141	64
244	.215	.273	.787	5040	87.8	92	106
245	.241	.261	.924	4900	84.5	71	85
244	.244	.248	.984	5000	86.0	102	96
245	.237	.240	.987	5180	89.1	96	85
245	.251	.240	1.046	5030	86.5	106	85
245	.243	.231	1.051	5210	89.5	91	79
248	.292	.214	1.365	4940	86.2	108	66
197	.146	.260	.562	4890	87.9	50	82
193	.174	.235	.741	4755	83.2	78	96
193	.196	.220	.891	4675	80.7	69	76
193	.233	.202	1.154	4470	77.3	84	71

TABLE IV. - 1.50-INCH-DIAMETER CHAMBER WITH 45-TUBE INJECTOR

[Spacing, 0.070 in.]

Chamber pressure, lb/sq in. abs	Oxidant flow, lb/sec	Fuel flow, lb/sec	Oxidant-fuel ratio	Characteristic velocity, c*, ft/sec	c* efficiency	Oxidant pressure drop	Fuel pressure drop
Contraction ratio, 6.25; characteristic length, 5 in.							
250	0.237	0.260	0.911	4440	76.6	130	109
258	.284	.237	1.198	4375	75.5	126	83
269	.341	.230	1.482	4160	73.5	85	37
217	.184	.290	.634	4040	71.7	63	80
222	.231	.267	.866	3935	68.2	56	70
216	.230	.243	.946	4030	69.5	72	66
193	.161	.242	.666	4225	74.7	73	54
192	.226	.230	.983	3715	64.1	71	84
188	.249	.212	1.175	3591	62.1	75	84
Contraction ratio, 3.52; characteristic length, 10 in.							
212	0.387	0.305	1.269	4895	85.1	47	109
208	.424	.281	1.508	4710	83.7	38	131
209	.470	.271	1.734	4500	82.3	40	163

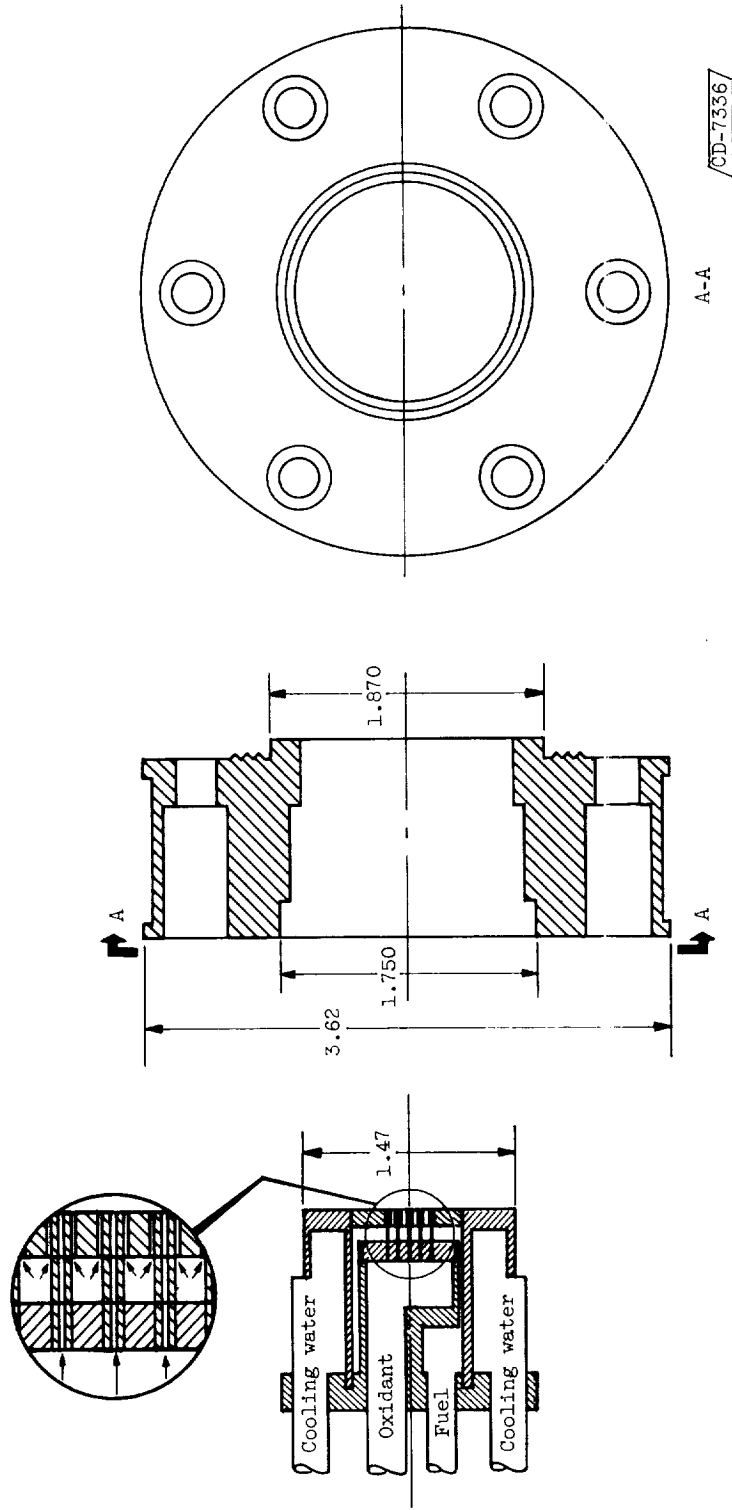


(b) Chamber segments.

Figure 2. - Nozzle and chamber segments.

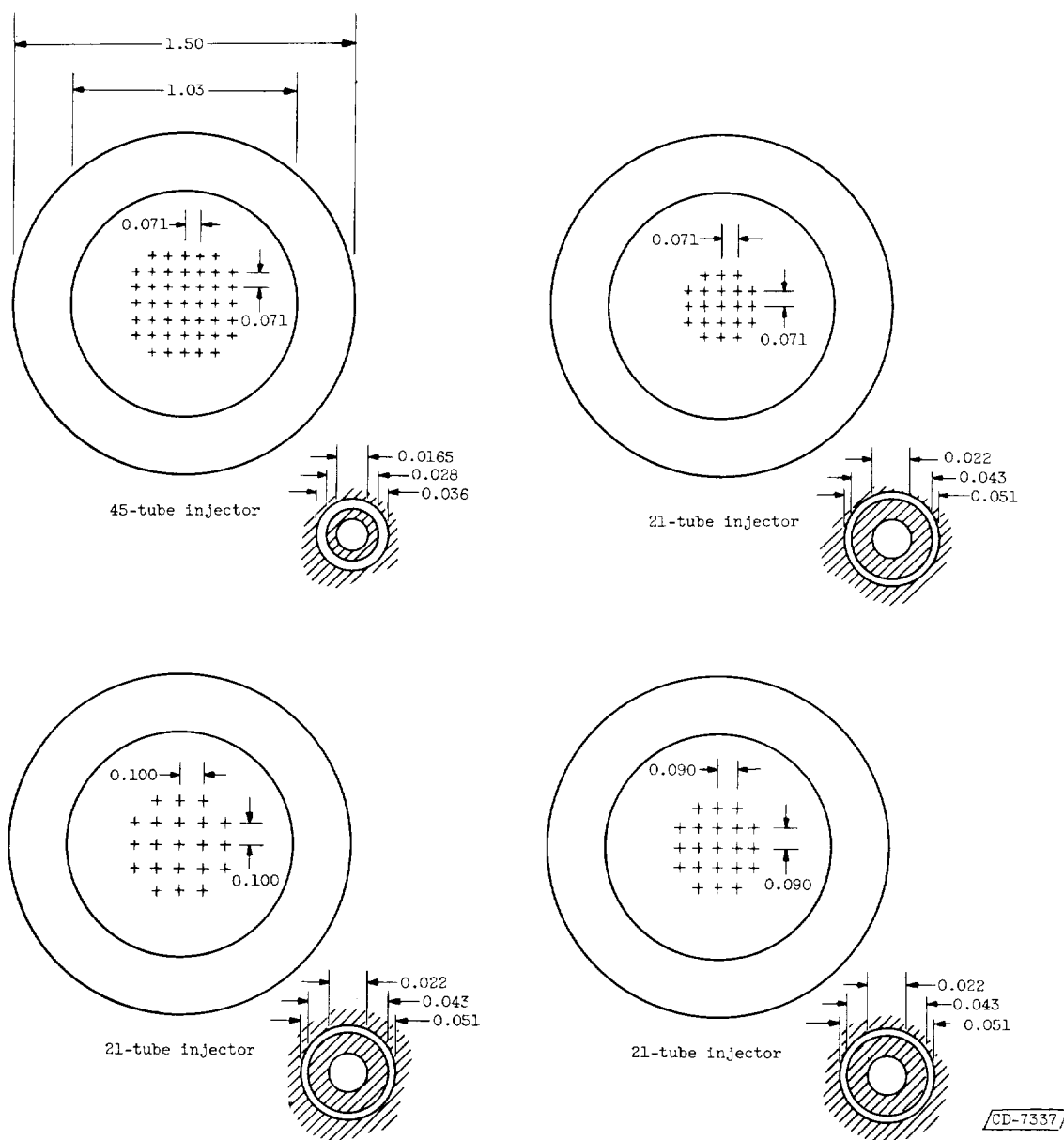
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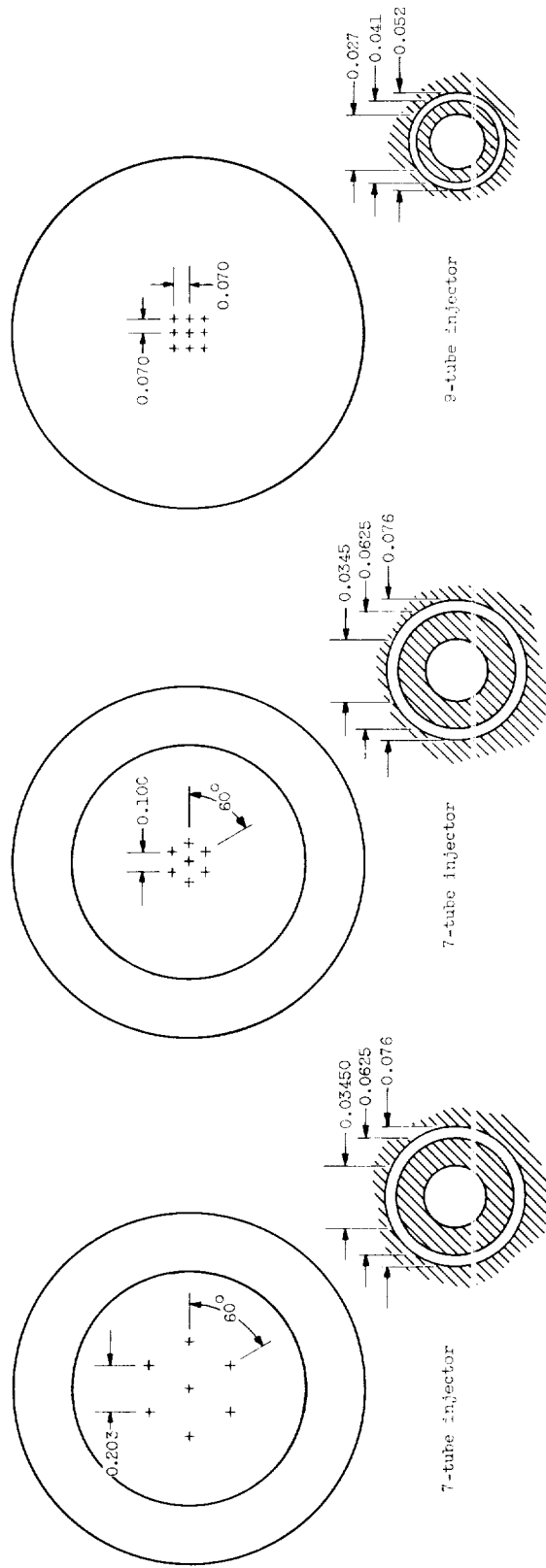
(a) Injector assembly.

Figure 3. - Injectors and assembly for 100-pound-thrust rocket motor. (Dimensions in inches.)



(b) 45- and 21-tube injector configurations.

Figure 3. - Continued. Injectors and assembly for 100-pound-thrust rocket motor. (Dimensions in inches.)



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(c) 9- and 7-tube injector configurations.  
Figure 3. - Concluded. Injectors and assembly for 100-pound-thrust rocket motor. (Dimensions in inches.)

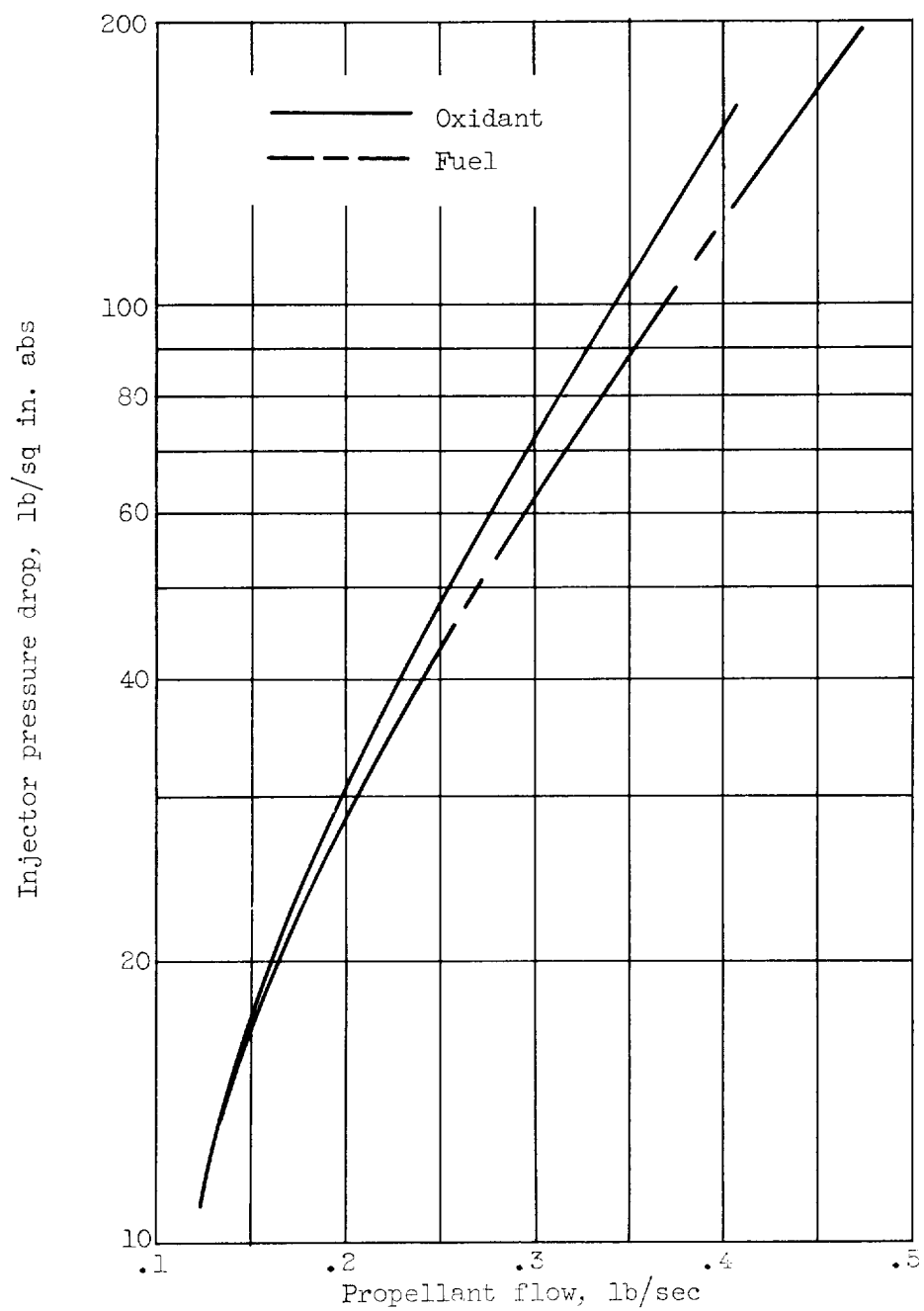
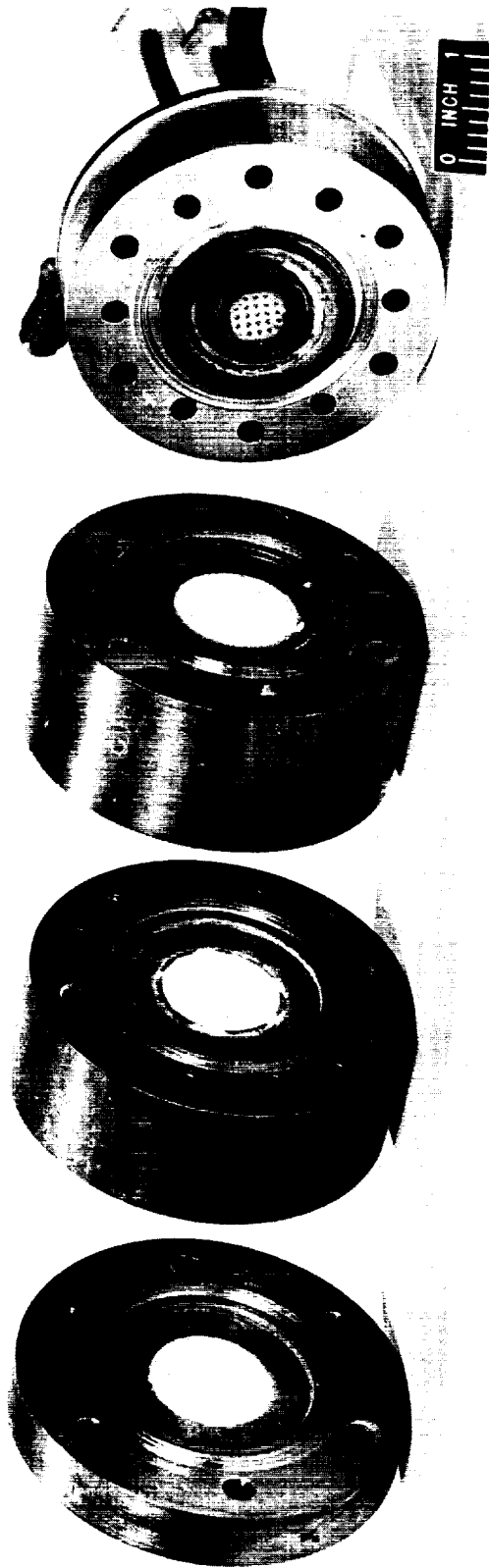
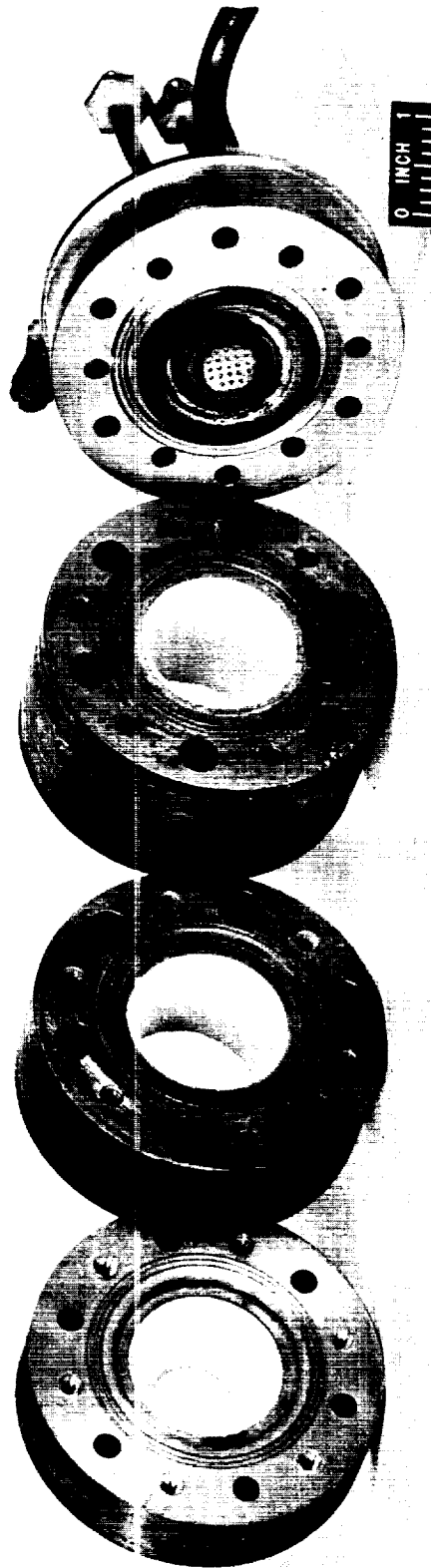


Figure 4. - Representative flow calibration for all injectors.



(a) 1.03-inch chamber.

C-54357



(b) 1.50-inch chamber.

C-54358

Figure 5. - Chamber segments.

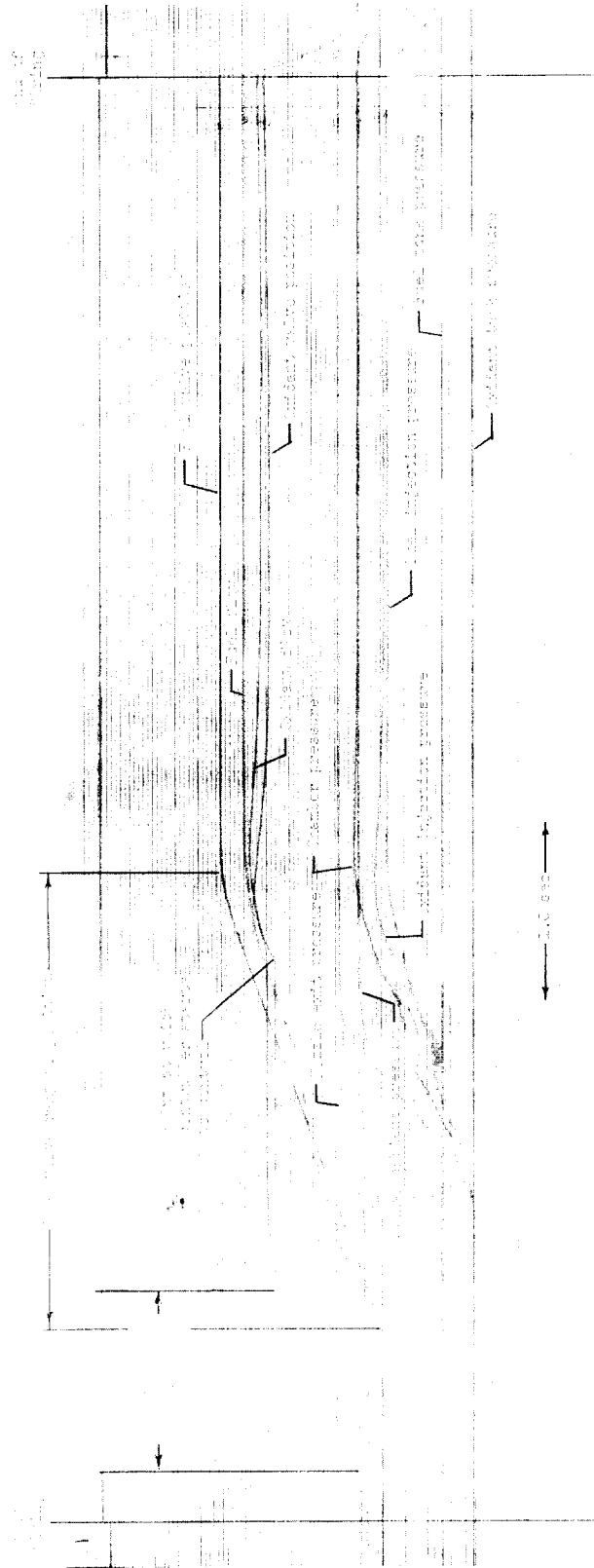


Figure 3. - Longitudinal section of rocket firing.

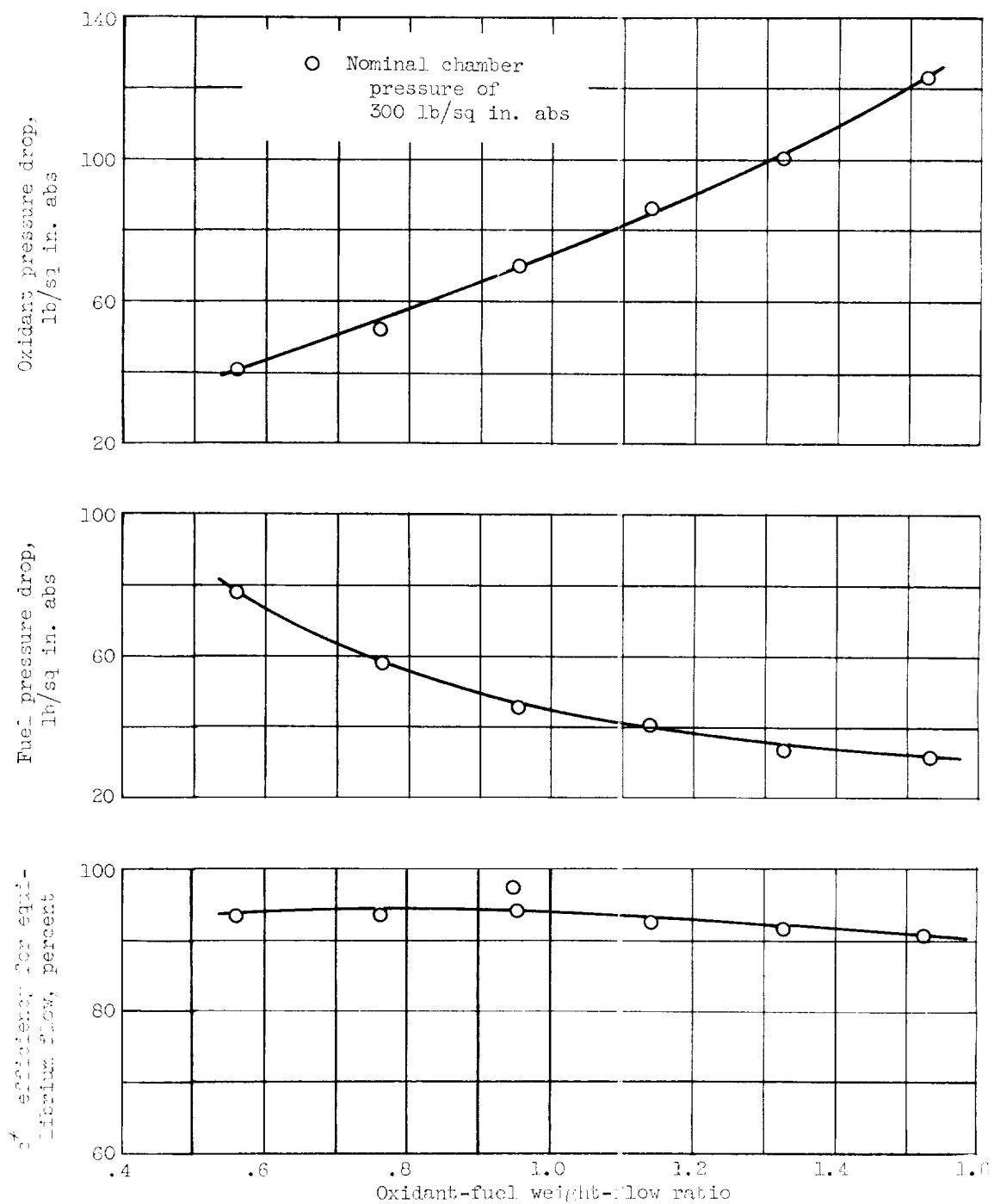
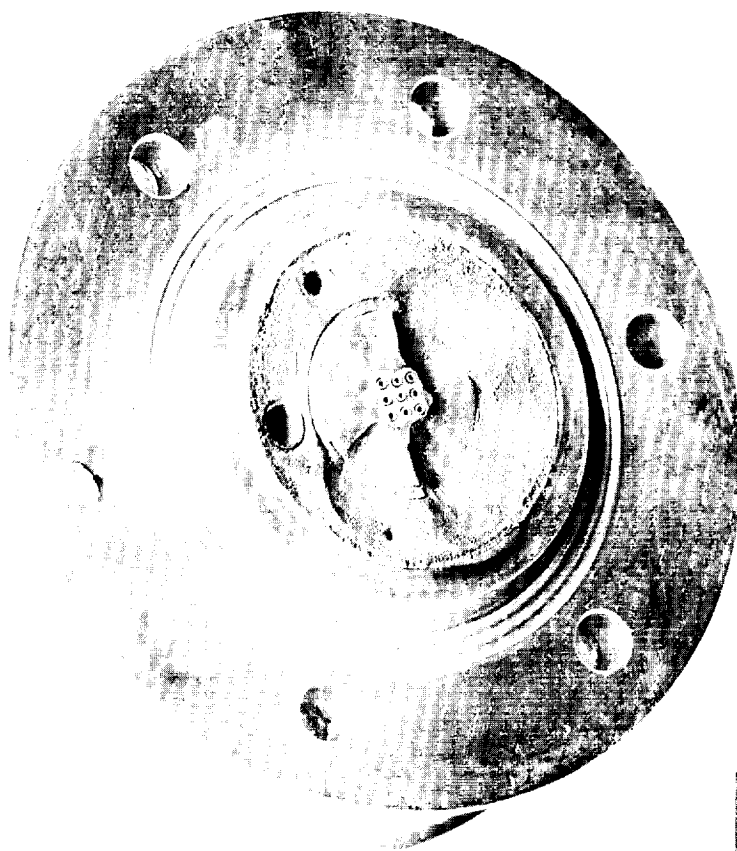


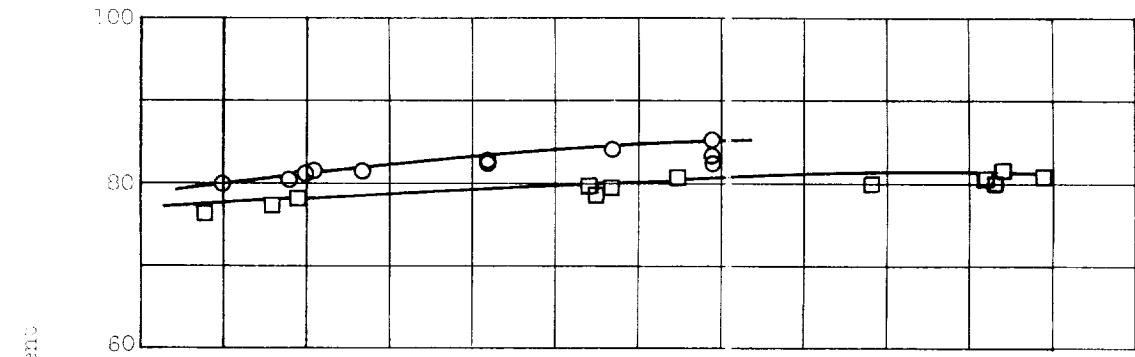
Figure 7. - Performance of 23-tube injector with 0.030-inch tube spacing. Chamber diameter, 1.03 inches; characteristic length, 10.7 inches; contraction ratio, 3.00.

E-1325

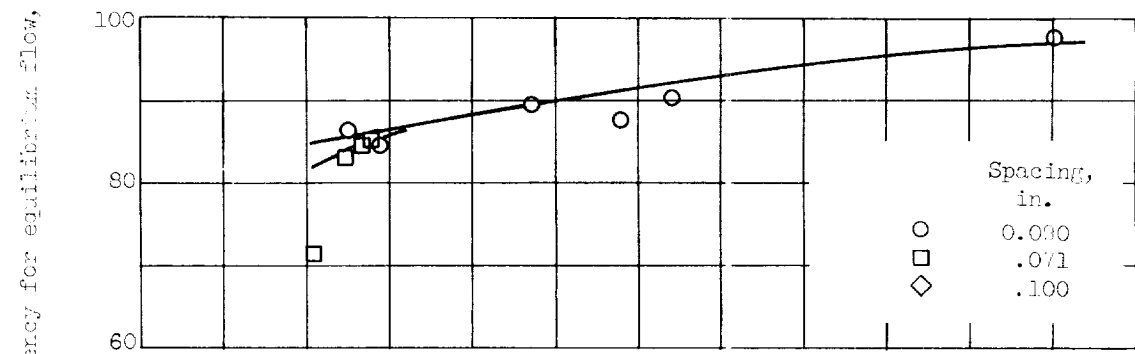


C-53185

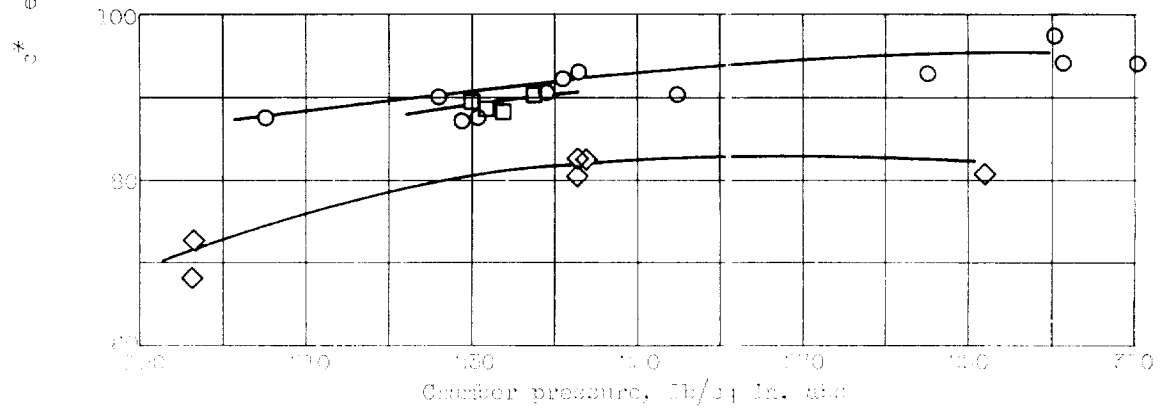
Figure 8. - Mine-tube injector face after burnout.



(a) Characteristic length, 6.15 inches; chamber length, 2.277 inches.



(b) Characteristic length, 3.70 inches; chamber length, 3.403 inches.



(c) Characteristic length, 10.40 inches; chamber length, 7.403 inches.

Figure 1. - Effect of injection point spacing in 12-rib injection. Configuration No. 740.

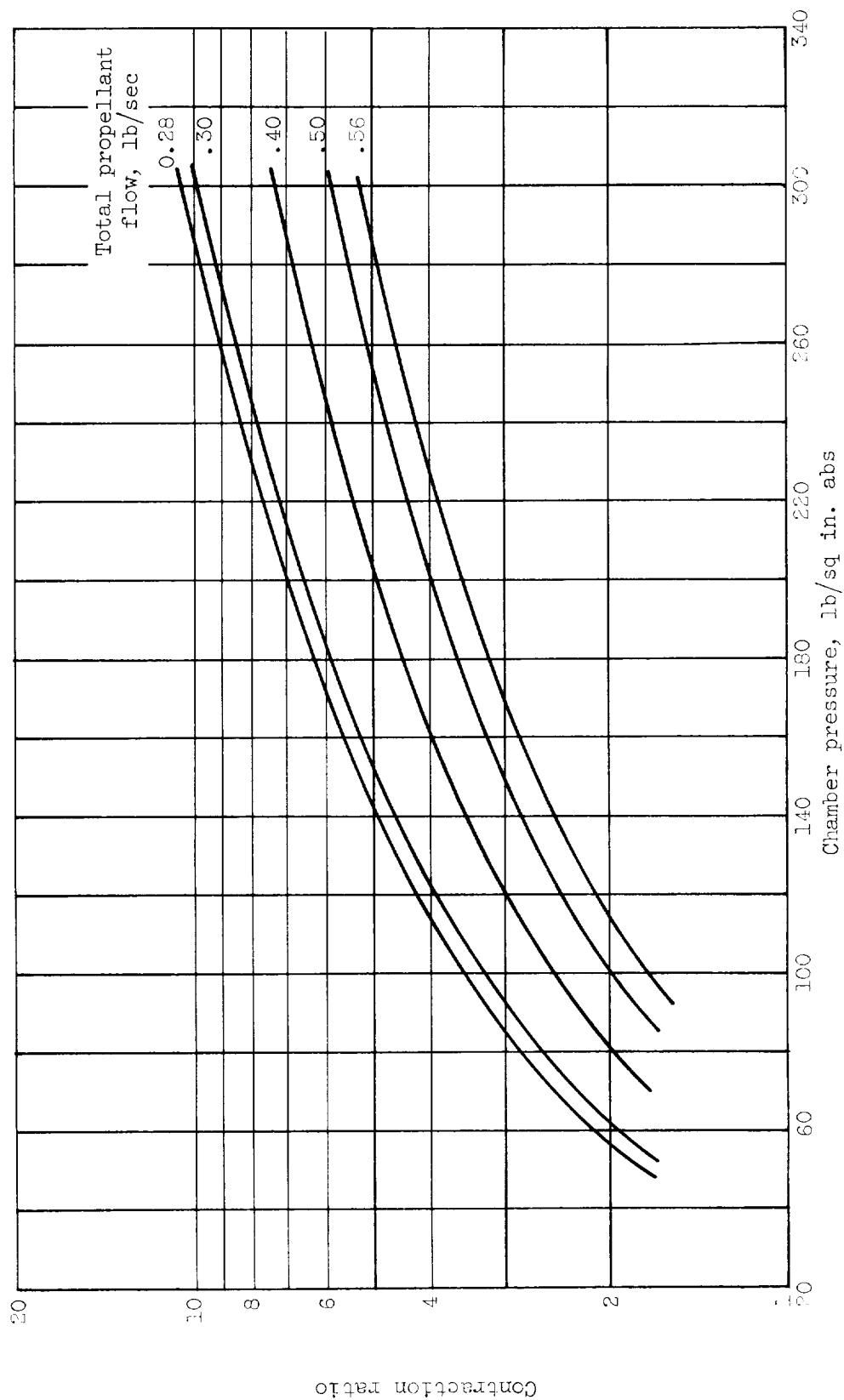
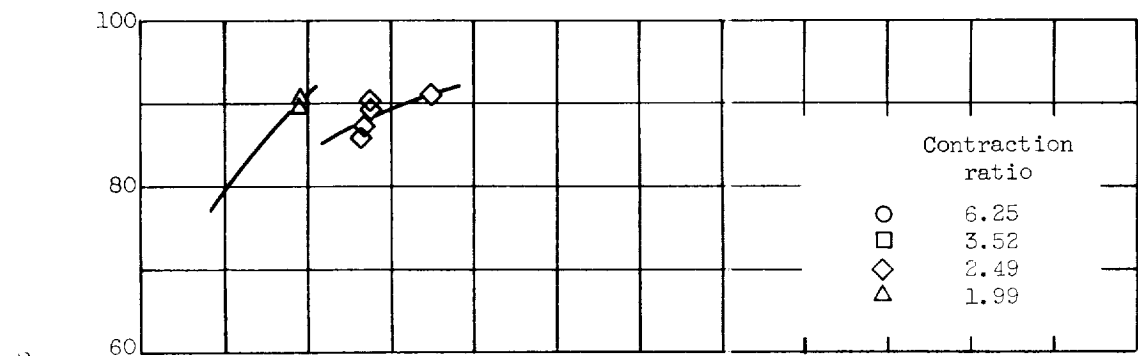
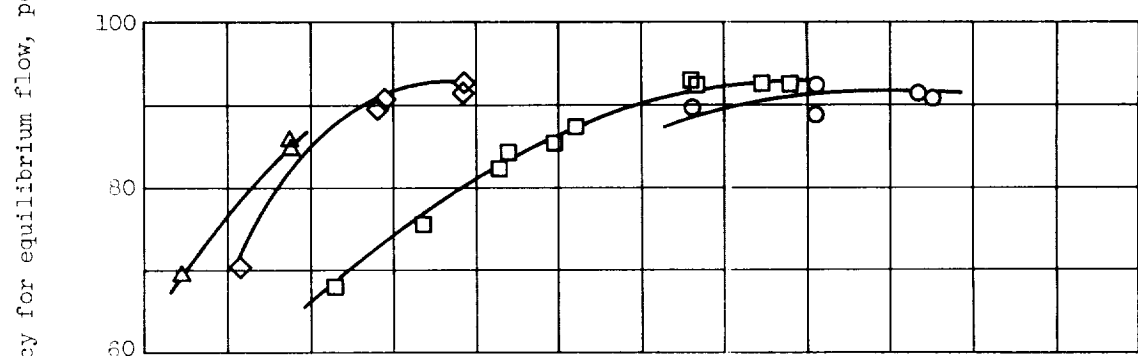


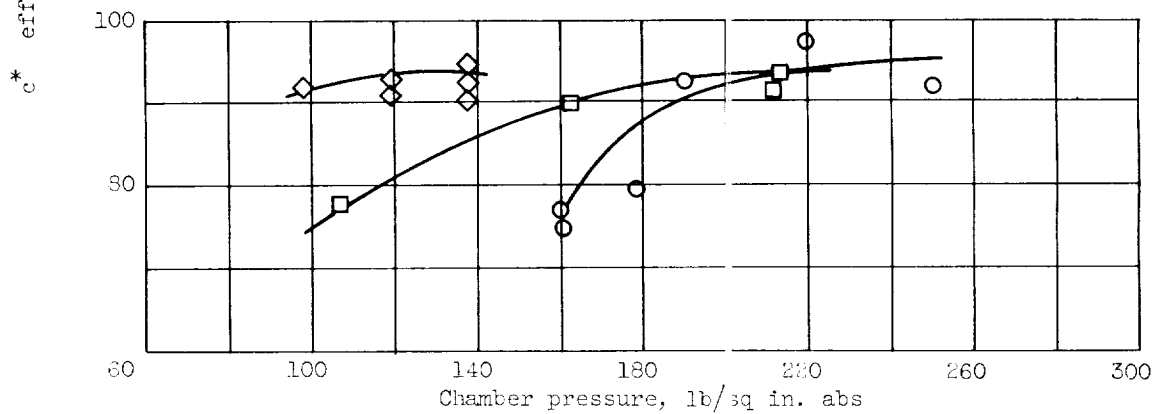
Figure 10. - Variation of contraction ratio with chamber pressure for constant total propellant flow.



(a) Characteristic length, 7.5 inches.



(b) Characteristic length, 10.0 inches.



(c) Characteristic length, 15.0 inches.

Figure 11. - Effect of chamber pressure on 21-tube injector for several contraction ratios and characteristic lengths.

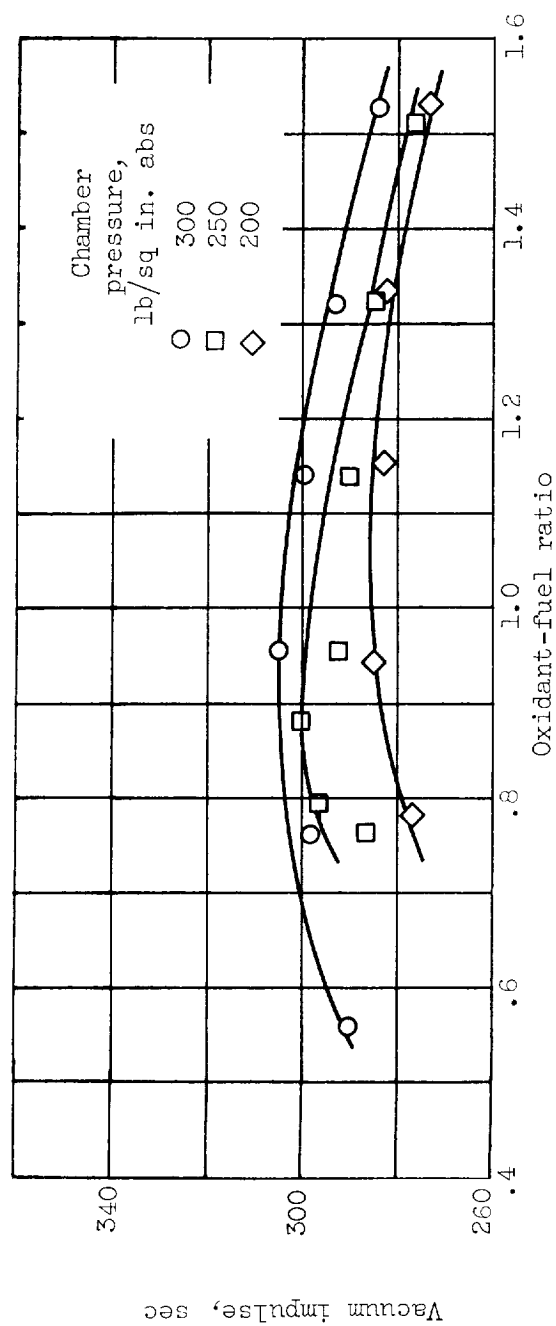


Figure 12. - Vacuum specific impulse based on experimental characteristic velocity for 21-tube injector with spacing of 0.090 inch. Chamber diameter, 1.03 inches; characteristic length, 10.7 inches; nozzle area ratio, 50; thrust coefficient, 1.8; ratio of specific heats, 1.30.

